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FOCUS ISSUE: CARDIAC IMAGING

Evaluation of Global and Regional Left Ventricular Function With 16-Slice Computed Tomography, Biplane Cineventriculography, and Two-Dimensional Transthoracic Echocardiography

Comparison With Magnetic Resonance Imaging

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OBJECTIVES We sought to compare left ventricular (LV) function assessed with multislice computed tomography (MSCT), biplane cineventriculography (CVG), and transthoracic echocardiography (Echo), with magnetic resonance imaging (MRI) as the reference standard.

BACKGROUND With the same data as acquired for noninvasive coronary angiography, MSCT enables registration of myocardial function.

METHODS A total of 88 patients (64 men and 24 women) underwent MSCT with 16 × 0.5 mm detector collimation, CVG, and MRI, whereas Echo was retrospectively analyzed in a subset of 30 patients.

RESULTS Regarding the ejection fraction, the agreement was significantly superior for MSCT than for CVG (± 10.2% vs. ± 16.8%; $p < 0.001$) and Echo (± 11.0% vs. ± 21.2%; $p < 0.001$). For the end-diastolic and end-systolic volumes, the limits of agreement with CVG ($p < 0.001$) and Echo ($p < 0.001$ and $p < 0.02$, respectively) were also significantly larger than with MSCT. In comparison with MSCT, CVG significantly overestimated the end-diastolic and end-systolic volumes ($p < 0.001$). Intraobserver analysis of MSCT yielded limits of agreement for ejection fraction (± 4.8%), end-diastolic volume (± 15.6 ml) and end-systolic volume (± 8.0 ml), and myocardial mass (± 18.2 g). The accuracy in identifying patients and myocardial segments with abnormal regional function was significantly higher with MSCT (84% and 95%) than with CVG (63% and 90%; $p < 0.002$ and $p < 0.001$), whereas MSCT and Echo were not significantly different in identifying patients with abnormal regional function.

CONCLUSIONS Our results indicate that the assessment of global and regional LV function with MSCT is more accurate than with CVG, whereas MSCT is superior to Echo for global function. This suggests that MSCT allows reliable evaluation of global and regional LV function. (J Am Coll Cardiol 2006;48:2034–44) © 2006 by the American College of Cardiology Foundation

To reliably evaluate global left ventricular (LV) function is of tremendous importance for determining the prognosis and therapeutic management in patients with known or suspected cardiac diseases (1–3). Two-dimensional (2D) transthoracic echocardiography (Echo) is currently the clinically most widely used method but is operator-dependant and might be impaired by a poor acoustic window and inadequate endocardial border discrimination in 5% to 10% of patients (4,5). Contrast biplane cineventriculography (CVG) can also assess global function as part of cardiac catheterization (e.g., for coronary angiography) (6,7). The drawbacks of CVG include the fact that it uses a projectional method that makes certain geometrical assumptions (8). Magnetic resonance imaging (MRI) is currently considered the reference standard for assessment of myocardial function (9,10). It now seems feasible to perform reliable noninvasive coronary angiography by using multislice computed tomography (MSCT) with at least 12 detector rows (11–16). It would be a clinically important advantage if the same data as acquired for noninvasive coronary angiography with MSCT could be also used to analyze LV function. Thus, we sought to compare the agreement and correlation of MSCT, CVG, and Echo with MRI as the reference standard for evaluation of global and regional LV function.

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METHODS

Patients. We prospectively studied 88 consecutive patients with suspected coronary artery disease who underwent MSCT, CVG, and MRI within 48 h. Echo with quantification was retrospectively analyzed in the subset of 30

Abbreviations and Acronyms

CVG = biplane cineventriculography
Echo = transthoracic echocardiography
LV = left ventricular/ventricle
MRI = magnetic resonance imaging
MSCT = multislice computed tomography

patients with suspected coronary artery disease who underwent a clinically indicated standardized in-house examination within 14 days of MRI. The clinical indications for Echo were angina pectoris (14 patients, 47%), shortness of breath (8 patients, 27%), arterial hypertension (6 patients, 20%), and pericardial effusion (2 patients, 7%). Magnetic resonance imaging served as the reference standard for comparison of MSCT, CVG, and Echo. The study group consisted of 64 men and 24 women (mean age 62 ± 9 years). Patients with renal insufficiency (creatinine of at least 1.5 mg/dl), known allergy to iodinated contrast agents, hyperthyroidism, unstable angina pectoris, cardiac arrhythmia, pregnancy, contraindications to MRI (e.g., pacemaker), coronary artery stents, or bypass grafts were excluded. Seventeen patients were smokers, 45 patients had hyperlipidemia, and 61 patients had arterial hypertension. The study protocol was approved by the institutional review board; all patients gave written informed consent. Beta-blockers were not administered for any of the 4 modalities to avoid alteration of cardiac volumes for functional analysis.

MRI. Magnetic resonance imaging was performed on a 1.5-T scanner (Magnetom Sonata, Siemens AG, Erlangen, Germany) equipped with a high-performance gradient subsystem (maximum amplitude = 40 mT/m and a minimum rise time of 0.2 ms) with a 12-element phased-array coil optimized for cardiac imaging. For cardiac synchronization and monitoring, 3 electrodes of an active ECG system were placed on the patient's anterior hemithorax. Cinematic magnetic resonance images were acquired along the 2- and 4-chamber view and in the short-axis orientations with a segmented true fast imaging and steady precession (True-FISP) sequence with asymmetric sampling of echoes with the following parameters: repetition time = 2.8 ms, echo time = 1.2 ms, slice thickness = 8 mm, no interslice gap, voxel size = 1.7 × 1.3 × 8 mm, acquisition window/phase = 34 ms (24 segments/phase), slice resolution = 100%, and flip angle = 54°. We chose a length of 34 ms for 1 phase, because the temporal resolution should be between 20 and 40 ms to allow accurate assessment of myocardial function with MRI (17). Parallel imaging (generalized autocalibrating partially parallel acquisitions) with an acceleration factor of 2 was employed (18). Two slices along the cardiac short-axis were acquired within 1 breath hold of 14 heartbeats, and the entire heart was covered from base to apex without gaps. Analysis of the global LV function parameters was performed by 1 reader blinded to the results of MSCT, CVG, and Echo with the short-axis slices with ARGUS according to Simpson's rule (Version 2002B, Siemens). For assessment of myocardial mass, the papillary muscles were assigned to the LV muscle (19,20). Basal slices with <180° circumferential LV muscle ring at end-systole were excluded from analysis as described recently (21). Regional LV function was assessed with a 4-point scale (1, normal; 2, hypokinesia; 3, akinesia; 4, dyskinesia) (22) for all 17 myocardial segments according to the American Heart Association (AHA) segmentation in each patient (23).

MSCT. Multislice computed tomography was performed during 1 breath hold on a 16-slice CT scanner (Aquilion, Toshiba, Otawara, Japan) with 400 ms gantry rotation time, 16 × 0.5 mm detector collimation, 0.35 × 0.35 mm^2 pixel size (10 line pairs/cm), 120 kV, 300 mA, and 0.2 pitch. The effective dose was estimated with CT-Expo Version 1.3 (24). A nonionic contrast agent (iodixanol, visipaque 320, 320 mg I/ml, GE-Healthcare Biosciences, Buckinghamshire, United Kingdom) was injected intravenously at a speed of 3.5 ml/s. The manual sure-start feature of the scanner was used to visualize the influx of the contrast medium (bolus-tracking) and to start image acquisition. Images were reconstructed with the multisegment approach (25) correlated with the raw data from up to 4 heartbeats (12) at 10 time points at 10% intervals with the center of the reconstruction window being between 0% and 90% of the cardiac cycle as described recently (26). The major determinant of image quality in cardiac MSCT is temporal resolution, which is defined by the image acquisition window. It was recently shown that cardiac function can be accurately assessed by MSCT with multisegment reconstruction without the need to alter heart rates by administration of

Table 1. Results of Correlation Analysis for MSCT and CVG as Compared With MRI for Evaluation of Global Left Ventricular Function in 88 Patients

	MRI	MSCT	CVG	MSCT vs. MRI	CVG vs. MRI
Ejection fraction (%)	65.3 ± 12.1	63.1 ± 12.1	63.3 ± 11.0	R = 0.91; p < 0.001; SEE = 5.1; slope = 0.91; intercept = 3.74	R = 0.73; p < 0.001; SEE = 7.5; slope = 0.66; intercept = 20.2
End-diastolic volume (ml)	100.8 ± 40.4	107.0 ± 40.1	180.7 ± 53.6	R = 0.87; p < 0.001; SEE = 20.0; slope = 0.86; intercept = 20.1	R = 0.77; p < 0.001; SEE = 34.2; slope = 1.02; intercept = 77.5
End-systolic volume (ml)	38.3 ± 31.8	43.5 ± 32.2	69.0 ± 39.5	R = 0.92; p < 0.001; SEE = 12.8; slope = 0.93; intercept = 7.9	R = 0.89; p < 0.001; SEE = 18.4; slope = 1.10; intercept = 26.8
Myocardial mass (g)	135.2 ± 49.2	131.1 ± 46.9	NA	R = 0.93; p < 0.001; SEE = 17.3; slope = 0.89; intercept = 11.3	NA

CVG = (biplane) cineventriculography; MRI = magnetic resonance imaging; MSCT = multislice computed tomography; NA = not applicable; SEE = standard error of the estimate.

Table 2. Results of Correlation Analysis for MSCT and Echo as Compared With MRI for Evaluation of Global Left Ventricular Function in 30 Patients

	MRI	MSCT	Echo	MSCT vs. MRI	Echo vs. MRI
Ejection fraction (%)	63.8 ± 14.3	60.8 ± 15.1	61.5 ± 11.6	R = 0.93; $p < 0.001$; SEE = 5.7; slope = 0.99; intercept = −2.1	R = 0.70; $p < 0.001$; SEE = 8.8; slope = 0.55; intercept = 26.7
End-diastolic volume (ml)	109.5 ± 57.8	118.8 ± 55.0	130.4 ± 55.7	R = 0.91; $p < 0.001$; SEE = 23.5; slope = 0.86; intercept = 24.1	R = 0.63; $p < 0.001$; SEE = 44.1; slope = 0.61; intercept = 63.9
End-systolic volume (ml)	46.0 ± 47.5	54.1 ± 45.8	50.5 ± 33.2	R = 0.94; $p < 0.001$; SEE = 16.0; slope = 0.91; intercept = 12.5	R = 0.85; $p < 0.001$; SEE = 17.9; slope = 0.59; intercept = 23.2

Echo = transthoracic echocardiography; other abbreviations as in Table 1.

beta-blockers (25). Thus, no beta-blockers were administered for MSCT and the other 3 functional modalities. The images reconstructed at the equidistant time points within the cardiac cycle enabled us to derive functional information from the MSCT data on the scanner's workstation with true contiguous 8-mm short-axis orientations and the volume method of the scanner's semi-automatic cardiac function analysis software as described (26). This volumetric approach allowed choosing the end-diastolic and end-systolic time points according to the LV volumes for all 10 time points. As with MRI, the automatically generated endocardial contours excluded the papillary muscles (26). In this way, 1 reader blinded to the results of MRI, CVG, and Echo calculated LV volumes according to Simpson's rule. Basal slices with <180° circumferential LV muscle ring at end-systole were excluded from analysis as described recently (21). Regional LV function was also assessed with the short-axis orientations and 2- and 4-chamber views with the 4-point scale for all 17 myocardial segments in each patient. Intraobserver variability for assessment of global and regional function with MSCT was evaluated for 29 randomly chosen data sets after a time delay of at least 6 months after the first reading.

CVG. Selective X-ray cineventriculography was performed with standard techniques with a frame rate of 30/s. Forty to 50 ml of a nonionic contrast agent was injected into the LV with a flow rate of 10 to 12 ml/s with a 5-F or 7-F pigtail catheter. An interventional cardiologist who was unaware of the MRI, MSCT, and Echo results analyzed LV function (Integris 3000, Philips Medical Systems, Bothel, Washington) on 2 orthogonal projections (30° right anterior oblique and 60° left anterior oblique) with the area-length method (8,27) and metallic spheres as calibration devices. In this way, absolute LV function values could be determined besides the ejection fraction. Regional LV function was also assessed with the 4-point scale for all 17 myocardial segments in each patient.

Echo. Echo was performed at a frame rate of 30/s with standard short-axis, 2- and 4-chamber views (GE Vingmed, Vivid 7 Dimension, Horton, Norway; 2.5-MHz transducer). Left ventricular end-diastolic and end-systolic volumes were calculated with the modified biplane Simpson method. One observer who was unaware of the MRI, MSCT, and CVG results traced the endocardial surface of the LV in 2 orthogonal planes (the apical 4-chamber and 2-chamber view) (5). Volumetric calculation was based on dividing the ventricular volume into a series of slices equidistant along the long axis of the ventricle, and built-in software allowed estimation of LV volumes even when the ventricles were distorted. Regional LV function was also assessed with the 4-point scale for all 17 myocardial segments in each patient.

Statistical analysis. All data are expressed as mean values ± SD unless otherwise noted. Pearson's correlation coefficient (28) and the limits of agreement (1.96 × SD = 95% confidence intervals [CIs]) determined with Bland-Altman analysis (29) served to compare global LV function parameters assessed by MSCT, CVG, and Echo with the reference standard MRI. For Bland-Altman analysis, a 2-tailed *F* test was used to analyze the equality of the resulting limits of agreement of the comparisons of MSCT, CVG, and Echo with MRI (9), and a 1-sample *t* test was used to analyze whether the mean differences from 0 (systematic under-estimation or overestimation of results) of MSCT, CVG, and Echo in comparison with MRI were significantly different from each other. Intraobserver variability for assessment of global function with MSCT was evaluated for 29 randomly chosen data sets by 1 reader after a time delay of at least 6 months after the first reading and was also analyzed with the limits of agreement (1.96 × SD = 95% CIs) determined with Bland-Altman analysis (29). The results of MRI served as the reference standard for assessing the sensitivity, specificity, accuracy, and negative and positive predictive values of MSCT, CVG, and Echo for detection of regional wall motion abnormalities in an intention-to-diagnose design (no patients or segments were excluded from analysis owing to inadequate image quality) (30). The pairwise McNemar's test and the chi-square test were used to compare the diagnostic accuracy in the detection of regional wall motion abnormalities on a 4-point scale (1, normal; 2, hypokinesia; 3, akinesia; 4, dyskinesia) (22) in a per-patient and per-segment analysis (with the 17-segment model of the AHA) (23) between MSCT, CVG, and Echo. Variability of regional function analysis with MSCT in comparison with MRI as the reference standard was measured with the pairwise McNemar's test and Cohen's kappa statistic. Statistical analyses were conducted with SPSS version

12.0 (SPSS, Chicago, Illinois). A p value <0.05 was considered significant.

RESULTS

Multislice computed tomography, CVG, and MRI were all performed without complications in any of the 88 patients. Echo was retrospectively analyzed in a subset of 30 patients. No clinically relevant cardiovascular events occurred between the procedures. For MSCT the patients had to hold their breath for 29 ± 3 s, and 18 patients (20%) received preoxygenation. The effective dose of MSCT was 12.2 ± 1.5 mSv and an amount of 108 ± 11 ml of contrast agent was administered. The width of the image acquisition window/R-R interval for MSCT was 148 ± 35 ms (median: 149 ms; range: 80 to 200 ms) at an average heart rate during scanning of 69.9 ± 10.8 beats/min, resulting in an image acquisition window of 17.2% of the R-R interval. On average 2.2 ± 0.6 segments (median: 2 segments; range: 1 to 3 segments) were used for multisegment reconstruction of MSCT. Fifty-seven (65%), 47 (53%), and 4 (13%) of the MSCT, CVG, and Echo examinations, respectively, were performed on the same day as the MRI. The mean interval between MSCT, CVG, and Echo and the reference standard MRI was 0.4 ± 0.7 days, 0.5 ± 0.5 days, and 1.1 ± 4.1 days, respectively. Forty-seven of the 88 patients had significant coronary artery disease as defined by conventional coronary angiography (at least one 50% diameter stenosis). Magnetic resonance imaging served as the reference standard for assessment of global and regional function with MSCT, CVG, and Echo.

LV ejection fraction. The ejection fraction showed significant correlations ($p < 0.001$) for the comparisons of MSCT, CVG, and Echo with the standard of reference

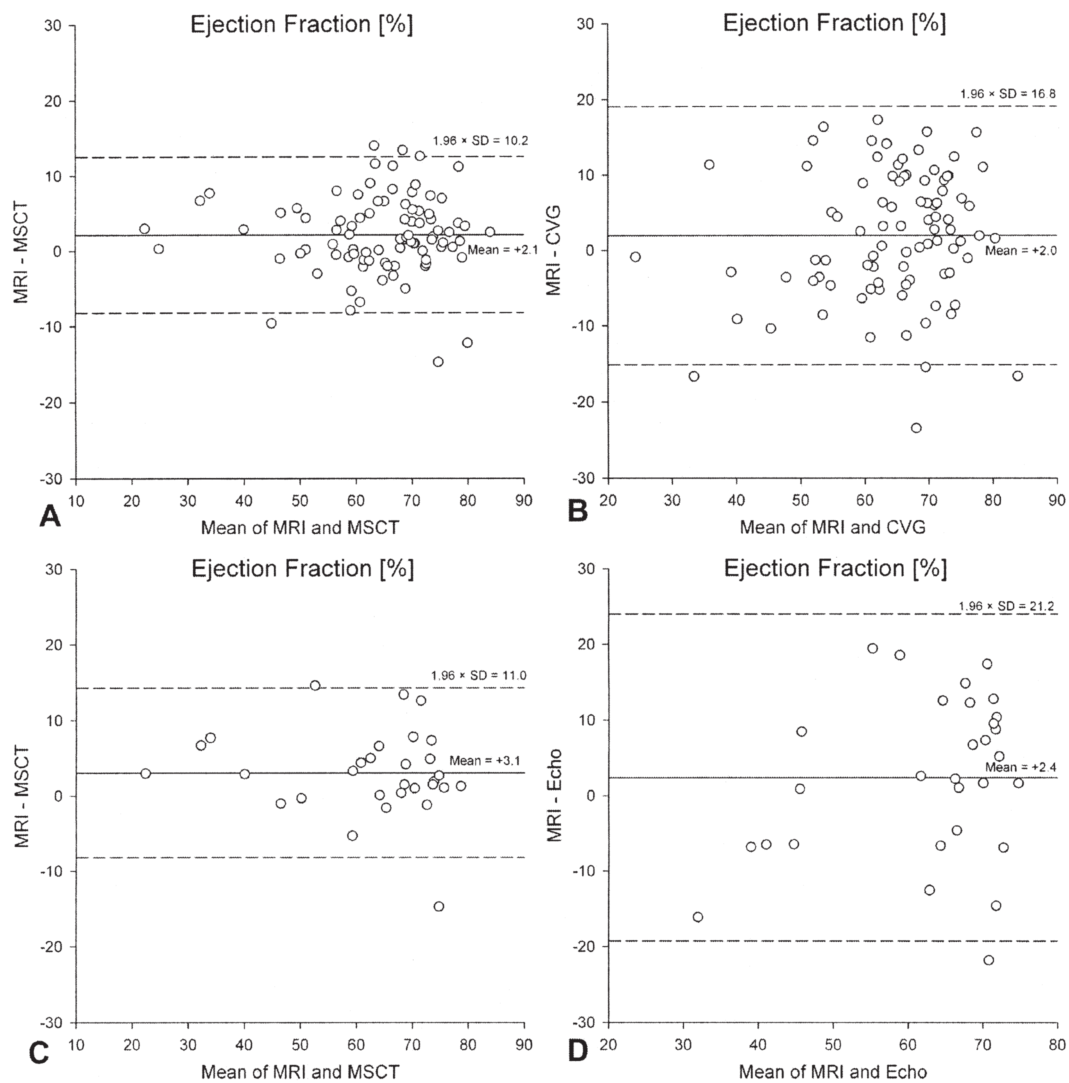

Figure 1. Agreement for assessment of ejection fraction between magnetic resonance imaging (MRI) and multislice computed tomography (MSCT) **(A)** and MRI and biplane cineventriculography (CVG) **(B)** in 88 patients. The agreement is also compared with the reference standard (MRI) for MSCT and transthoracic echocardiography (Echo) **(C and D)** in the subset of 30 patients who underwent Echo. The mean of the 2 methods compared is always plotted against the difference of the 2. The **solid line** is the mean of the differences, whereas the **dashed lines** mark the limit of agreement (95% confidence intervals = 1.96 × SD) according to Bland and Altman (29). There were significantly larger limits of agreement for the comparison of CVG and Echo with MRI **(B and D)** than for the comparisons of MSCT with MRI **(A and C)**.

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with a higher correlation and slope for MSCT, whereas the intercepts (differences of the regression line from 0 on the y-axis) were larger for CVG and Echo (Tables 1 and 2). In Bland-Altman analysis, the limits of agreement (95% CIs) for MSCT were significantly smaller than for CVG (± 10.2% vs. ± 16.8%; $p < 0.001$ with the F test) and Echo (± 11.0% vs. ± 21.2%; $p < 0.001$ with the F test) (Fig. 1).

LV end-diastolic and end-systolic volume. The end-diastolic and end-systolic volumes showed significant correlations ($p < 0.001$) for the comparisons of MSCT, CVG, and Echo with MRI, again with larger intercepts for CVG and Echo (Tables 1 and 2). In Bland-Altman analysis, there were significantly larger limits of agreement for CVG (± 66.7 ml) than for MSCT (± 40.5 ml; $p < 0.001$) and there was also a significantly larger overestimation of the end-diastolic volume with CVG (80 ml) than with MSCT (6.2 ml; $p < 0.001$ with the t test; Figs. 2A and 2B). In Bland-Altman analysis, the limits of agreement for MSCT were significantly smaller than for Echo (± 47.8 ml vs. ± 95.8 ml; $p < 0.001$ with the F test) (Figs. 2C and 2D). Bland-Altman analysis also demonstrated significantly larger limits of agreement for the assessment of end-systolic volume with Echo (± 51.2 ml) than with MSCT (± 32.1 ml; $p < 0.02$ with the F test) (Figs. 3C and 3D). There were also significantly larger limits of agreement for end-systolic volume with CVG (± 36.4 ml) than with MSCT (± 25.3 ml; $p < 0.001$ with the F test) (Figs. 3A and 3B). The mean of the differences of end-systolic volume in Bland-Altman analysis had a significantly larger deviation from 0 for CVG

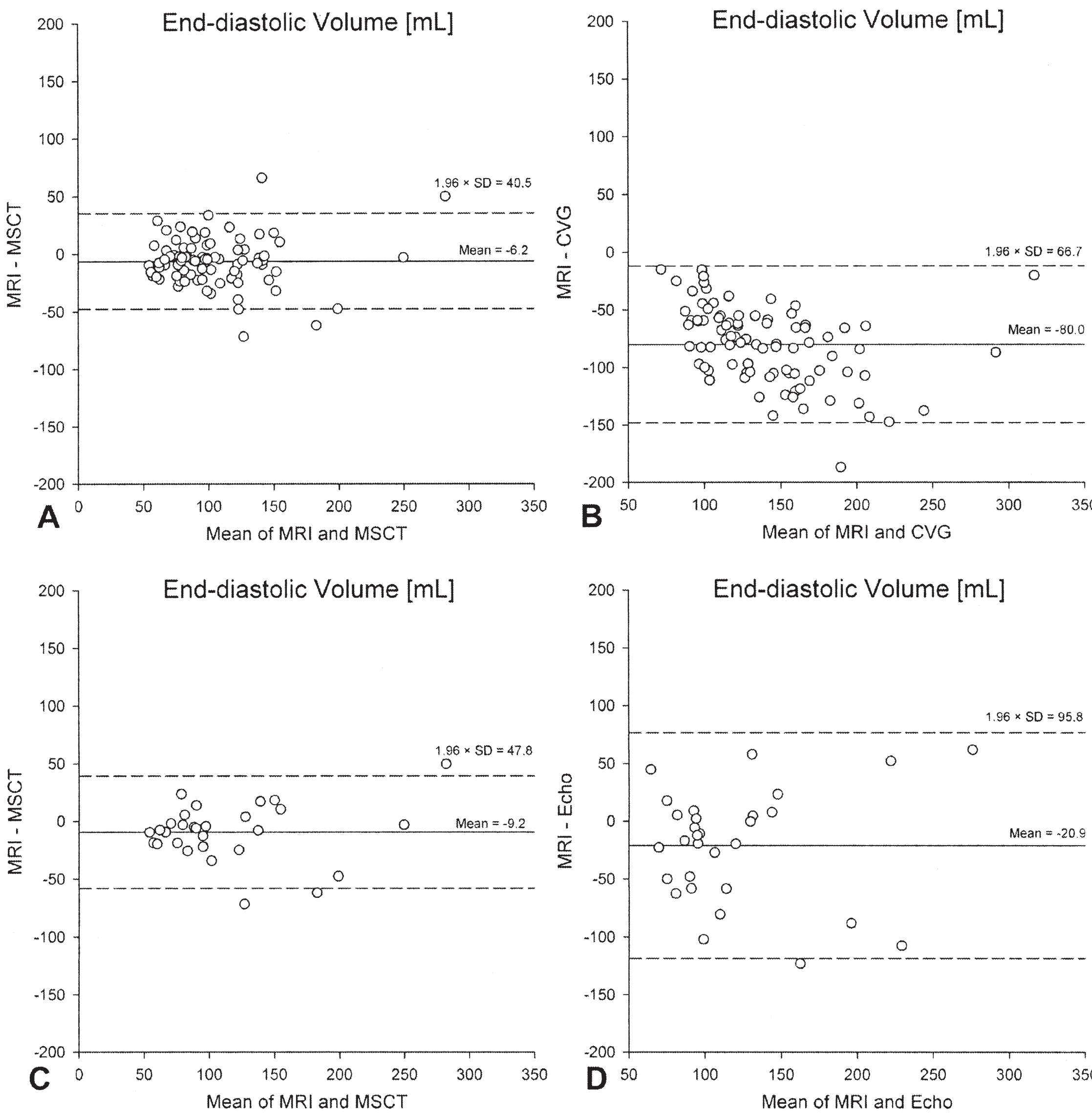

Figure 2. Agreement for assessment of end-diastolic volume between MRI and MSCT **(A)** and MRI and CVG **(B)** in 88 patients. The agreement is also compared with the reference standard (MRI) for MSCT and Echo **(C and D)** in the subset of 30 patients according to Bland and Altman as described in Figure 1. There were significantly larger limits of agreement for the comparison of CVG and Echo with MRI **(B and D)** than for the comparisons of MSCT with MRI **(A and C)**, and there was also a significantly larger overestimation of the end-diastolic volume with CVG than with MSCT **(A and B)**. Abbreviations as in Figure 1.

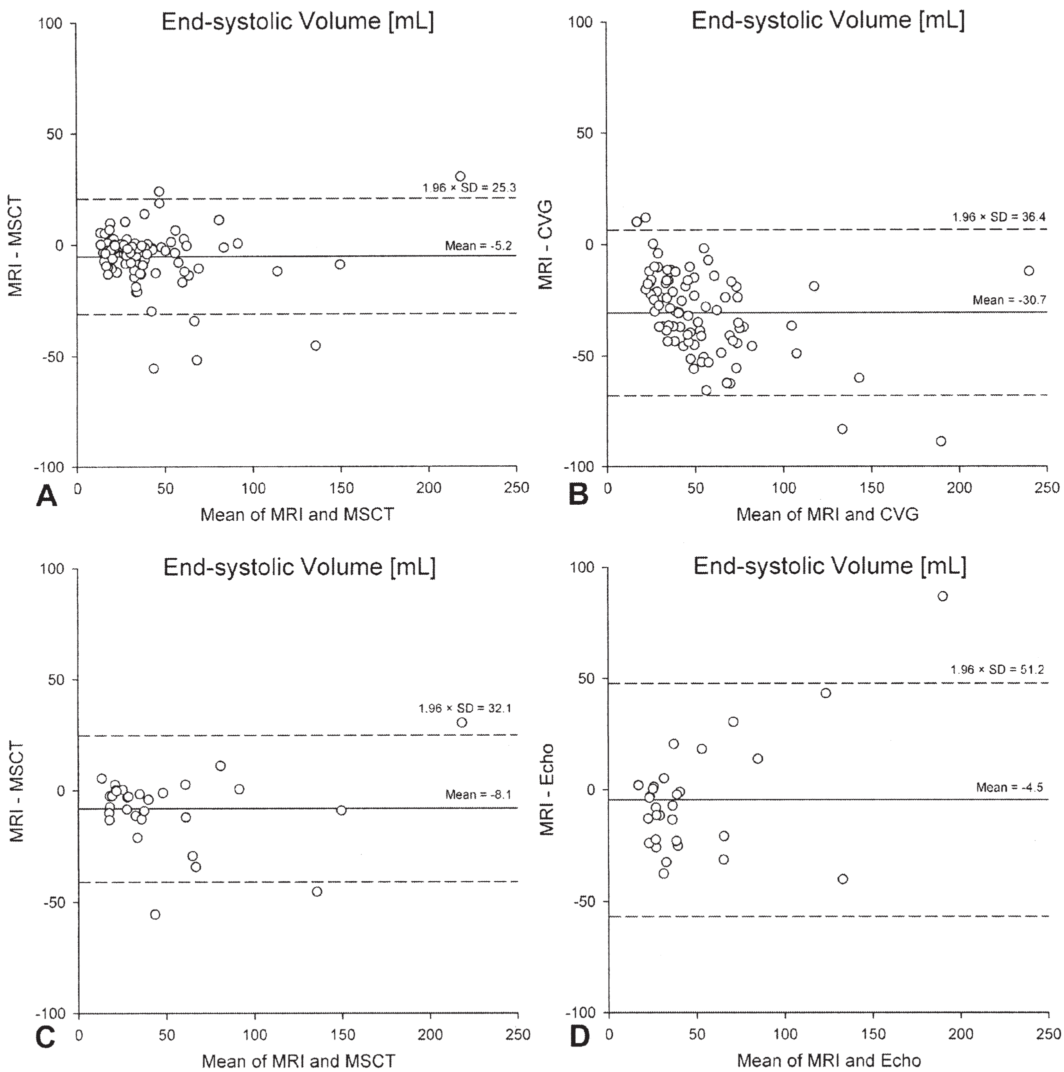

Figure 3. Agreement for assessment of end-systolic volume between MRI and MSCT **(A)** and MRI and CVG **(B)** in 88 patients. The agreement is also compared with the reference standard (MRI) for MSCT and Echo **(C and D)** in the subset of 30 patients according to Bland and Altman as described in Figure 1. There were significantly larger limits of agreement for the comparison of CVG and Echo with MRI than for the comparisons of MSCT with MRI, and there was also a significantly larger overestimation of the end-systolic volume with CVG than with MSCT. Abbreviations as in Figure 1.

(30.7 ml) than with MSCT (5.2 ml, $p < 0.001$ with the *t* test) (Figs. 3A and 3B).

LV myocardial mass. For assessment of myocardial mass, only MSCT could be compared meaningfully with MRI (31), and this comparison resulted in limits of agreement of ± 35.4 g (Fig. 4). Linear regression analysis revealed significant linear correlations, a slope of 0.89, and an r value of 0.93 for this comparison ($p < 0.001$) (Table 1).

Intraobserver variability. For the 29 randomly selected patients who had intraobserver variability of MSCT analyzed after an interval of at least 6 months, the limits of agreement for ejection fraction, end-diastolic volume, end-systolic volume, and myocardial mass were ± 4.8%, ± 15.6 ml, ± 8.0 ml, and ± 18.2 g, respectively, demonstrating a low variability for MSCT (Figs. 4 and 5).

Per-patient regional function. Magnetic resonance imaging demonstrated at least 1 myocardial segment with a wall motion deficit in 34 of the 88 patients. An example of a regional wall motion abnormality as detected with all 4 diagnostic methods is shown in Figure 6 (see the Appendix for supplementary video files). The sensitivity of MSCT to identify these patients (76% [26 of 34 patients]) was significantly higher ($p < 0.02$) than that of CVG (47% [16 of 34 patients]). Regarding the differentiation of patients with and without wall motion abnormalities, Cohen's kappa values for MSCT and CVG in comparison with MRI were 0.66 and 0.20, respectively, indicating moderate and poor agreement. The accuracy and specificity of MSCT (84% [74 of 88 patients] and 89% [48 of 54 patients]) were also significantly higher ($p < 0.002$ and $p < 0.03$, respectively) than that for CVG (63% [55 of 88 patients] and 72% [39 of 54 patients]). In contrast, the overall diagnostic accuracy of MSCT and Echo was not significantly different ($p = 0.51$ with the pairwise McNemar's test) with sensitivities of 78% (14 of 18 patients) and 67% (12 of 18 patients), respectively. Multislice computed tomography and Echo correctly iden-

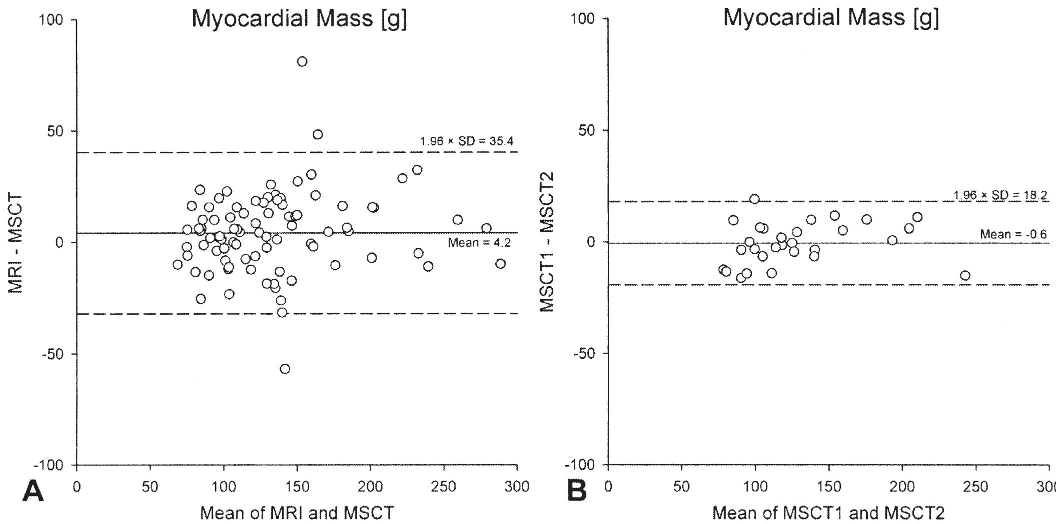

Figure 4. Agreement for assessment of myocardial mass between MRI and MSCT **(A)** and intraobserver agreement for MSCT **(B)**. Abbreviations as in Figure 1.

tified 10 and 11 of the 12 patients without wall motion deficits, respectively. Of the 29 patients analyzed a second time with MSCT, 90% (26 patients) were assigned to the same category as during the first analysis; the pairwise McNemar's test showed no significant differences between the 2 assessments, and Cohen's kappa was 0.79, indicating good assessment agreement with MSCT.

Per-segment regional function. In the 1,496 myocardial segments (in 88 patients) that were assessed for regional wall motion deficits with MRI, MSCT, and CVG, the sensitivity to detect any abnormality (a score of at least 2) was 75% for MSCT (100 of 133) and 38% for CVG (51 of 133; $p < 0.001$ with chi-square test). The accuracy and specificity of MSCT (94.9% [1,419 of 1,496 segments] and 96.8% [1,319 of 1,363 segments], respectively) were also significantly higher ($p < 0.001$ and $p < 0.007$, respectively) than that for CVG (89.6% [1,341 of 1,496 segments] and 94.6% [1,290 of 1,363 segments], respectively). Regarding the exact classification according to the 4-point scoring system, Cohen's kappa values for MSCT and CVG in comparison with MRI were 0.67 and 0.30, respectively, indicating moderate and poor agreement. The agreement for all myocardial segments on the 4-point scale was 94.3% (1,410 of 1,496 segments) and 88.7% (1,327 of 1,496 segments) with MSCT and CVG, respectively, and the McNemar's test showed significant differences in the overall assessment between MSCT and CVG ($p < 0.001$). For Echo, 510 myocardial segments were analyzed for regional wall motion deficits, and agreement on the 4-point scale was 91.0% (464 of 510 segments) and 80.0% (408 of 510 segments) with MSCT and Echo, respectively; and the pairwise McNemar's test showed significant differences in the overall assessment between MSCT and Echo ($p < 0.007$). Moreover, the sensitivity and accuracy of MSCT (80.5% [70 of 87 segments] and 92.0% [469 of 510 segments], respectively) were significantly higher (both $p < 0.001$) than those for Echo (39.1% [34 of 87 segments] and 82.7% [422 of 510 segments], respectively), whereas the specificities were not significantly different (94.3% [399 of 423 segments] vs. 91.7% [388 of 423 segments]; $p = 0.14$). Of the 493 myocardial segments (in 29 patients) analyzed a second time with MSCT, 96.8% (477 segments) were assigned to the same category on the 4-point scale as during the first analysis, the pairwise McNemar's test showed no significant differences between the assessments, and Cohen's kappa was 0.82, indicating good assessment agreement with MSCT also in the per-segment analysis.

DISCUSSION

Multislice computed tomography is an emerging modality for the noninvasive assessment of cardiac anatomy and function. This study showed for the first time that the evaluation of global and regional LV function with MSCT is more accurate than CVG in comparison with MRI as the reference standard. There was no significant difference of MSCT with Echo in identifying patients with abnormal regional function, whereas the agreement for assessment of ejection fraction and end-diastolic and end-systolic volume was significantly superior with MSCT. The variability of MSCT in determining global and regional LV function was proven to be sufficiently small for clinical application. Given that accurate noninvasive coronary angiography has become feasible with MSCT with at least 12 detector rows (11–16), the results of the present study have relevant clinical implications because it has become possible to perform a combined assessment of the coronary arteries and LV function noninvasively with the same data acquired within a single breath hold MSCT examination.

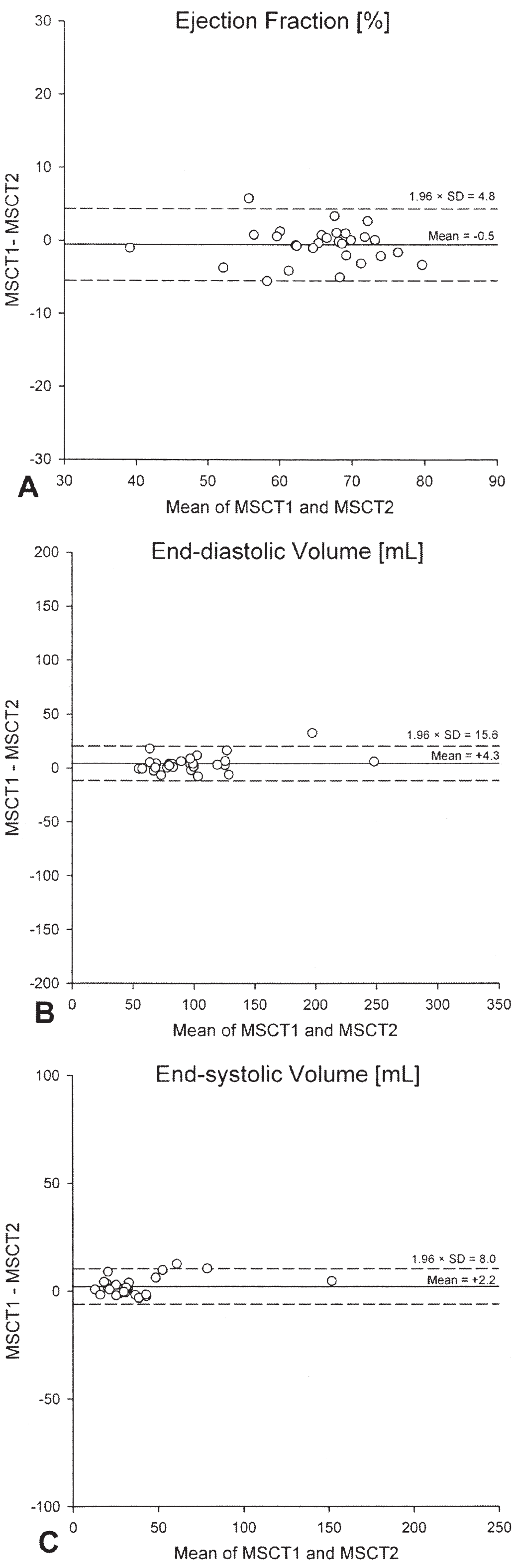

Figure 5. Intraobserver agreement for assessment of ejection fraction **(A)**, end-diastolic volume **(B)**, and end-systolic volume **(C)** with MSCT in 29 patients randomly selected from the entire patient cohort. For all intraobserver analyses, the limits of agreement and the deviations from 0 were significantly smaller than for the comparison of MSCT with MRI (all $p < 0.004$) in the same 29 patients, demonstrating a low variability with MSCT. Abbreviations as in Figure 1.

Comparison with previous studies. The LV ejection fraction that could be assessed with CVG compared with MRI with limits of agreement (± 17%) comparable to those reported in previous studies (± 19% [9] and ± 24% [32]). However, from previous head-to-head comparisons with MRI, it is well known that end-diastolic and end-systolic volumes are systematically overestimated by cineventriculography (9,27,33) as a result of geometric assumptions (8) and the angiographic magnification error (34). These observations were confirmed by the present study. Moreover, the assessment of regional LV function was more accurate with the cross-sectional modality MSCT than with CVG, which can be explained by the projectional nature of the CVG data. For this reason, CVG is especially limited in the detection of lateral and septal wall motion abnormalities as shown in a comparison of CVG with Echo as another cross-sectional imaging modality (35). The limits of agreement between CVG and MRI are too wide for reliable interchangeability of the LV volumes determined by both methods (e.g., within clinical studies for assessment of the effect of therapeutic interventions on myocardial function). Bellenger et al. (10) have shown in 52 patients that the interchangeability of different methods for assessment of myocardial function is very limited, especially for MRI, 2D Echo, and radionuclide ventriculography. Our results suggest, like those reported by Buck et al. (9) in 23 patients, that this holds also true for the comparison of CVG, Echo, and MRI in assessing end-diastolic and end-systolic volumes. In contrast, all global LV volumes can be reliably and interchangeably measured with MSCT and show significant correlation and good agreement with MRI, as reported in previous studies (21,36–39). Thus, MSCT might be used as an alternative in patients with a poor acoustic window in Echo or contraindications to MRI for evaluating global and regional LV function or in combination with noninvasive coronary angiography.

The agreement of MSCT with MRI in evaluating global and regional LV function might be further improved with shorter gantry rotation times. The average length of the image acquisition window/heartbeat achieved in the present study (148 ms) is considerably shorter than the one achieved in a previous study (208 ms) (21). Nevertheless, MSCT is still far from the temporal resolution that is necessary for optimal detection of the end-systolic period (length of the image acquisition window of about 20 to 50 ms) (17,40).

Regarding intraobserver variability, the limits of agreement of MSCT for ejection fraction, end-diastolic volume, and end-systolic volume (± 4.8%, ± 15.6 ml, ± 8.0 ml, respectively) are comparable to those reported by Buck et al. (9) for three-dimensional (3D) Echo (± 5.4%, ± 12.4 ml, ± 7.8 ml, respectively). Kühl et al. (41) recently reported slightly larger intraobserver limits of agreement for ejection fraction with real-time 3D Echo with a semi-automatic analysis tool (± 8.2%). The intraobserver variability for end-diastolic and end-systolic volumes with MRI is slightly

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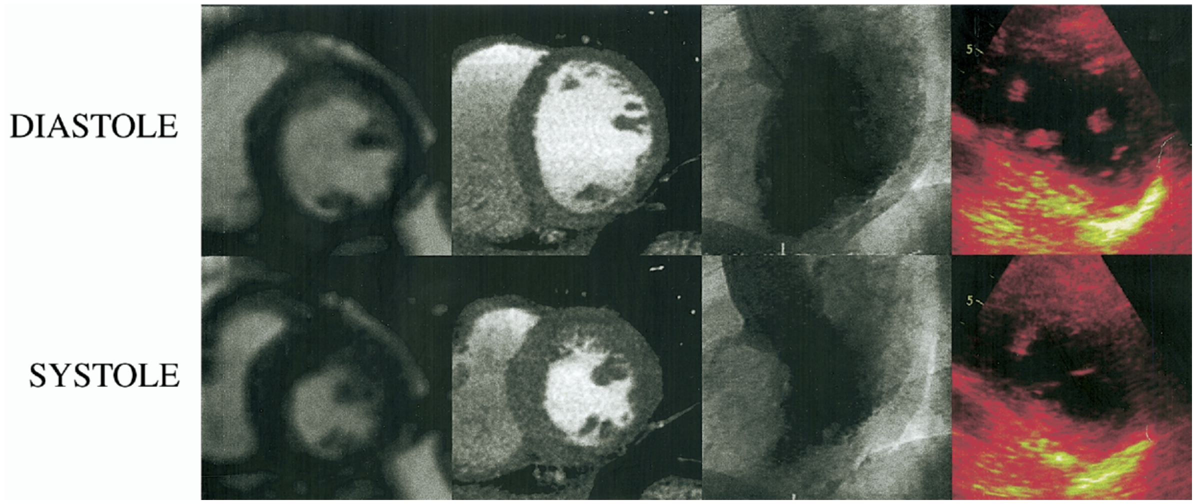

Figure 6. Example of a 48-year-old male patient with akinesia of the posterolateral wall on MRI (**first column**, short-axis view), MSCT (**second column**, short-axis view), CVG (**third column**, left anterior oblique view), and Echo (**last column**, short-axis view). Abbreviations as in Figure 1.

better than that of 3D Echo and MSCT as reported by Lorenz et al. (19) on the basis of 6 subjects with limits of agreement of ± 7.6 ml and ± 4.6 ml, respectively. Contrast and noncontrast 2D Echo were recently shown to have sufficiently small limits of agreement for ejection fraction in intraobserver analysis of ± 2.6% and 9.4%, respectively (4). Moreover, interobserver variability can also be significantly reduced with contrast administration for Echo (42). Intraobserver agreement for per-patient and per-segment regional function was sufficiently high in our study (90% and 96.8%, respectively) to allow reliable evaluation with MSCT.

Nowadays, Echo is the most widely used technique for evaluating LV function. In routine use, Echo offers some important advantages when compared with the other diagnostic tests: it can be easily performed at the bedside as a rapid screening tool, does not expose the patients to radiation, and it is inexpensive. Noncontrast 2D Echo in comparison with MRI has been reported in a multicenter trial involving 55 patients to be fairly accurate for assessment of ejection fraction with limits of agreement of ± 21.6% (42). These values are in the same range as in our study for the comparison of MRI and Echo (± 21.2%). With contrast application, the limits of agreement of 2D Echo for ejection fraction can be reduced to ± 17.4% (42), whereas MSCT has demonstrated in the present study limits of agreement of ± 10.2%.

Study limitations. The present study is, to our best knowledge, the first head-to-head comparison of MSCT, CVG, and Echo with MRI as the reference standard, but it had limitations. All patients included had suspected coronary artery disease, and the majority of the patients had a global cardiac function in a normal range (16 patients had myocardial infarction, 23 patients had an ejection fraction of <60% on MRI). Therefore, results of the study cannot be generalized to all cardiac patients, especially those with chronic myocardial infarction and remodeled ventricles. However, consecutive patients were included, and the results are valid for the comparison of MRI, MSCT, CVG, and Echo in patients with suspected coronary artery disease. We did not compare MSCT of global and regional function with 3D Echo or contrast 2D Echo, which has been shown to improve assessment (9,42,43), but with CVG, 2D Echo, and MRI. Echo was only performed in a subset of 30 patients. With standard halfscan reconstruction, the average length of the image acquisition window is 30% of the R-R interval, whereas with multisegment reconstruction this length, which defines the temporal resolution, can be improved to 17% of the R-R interval (25). Given this temporal resolution of MSCT, it becomes obvious that there is no benefit to be expected from more than 10 reconstruction time points within each R-R interval because, with 10 reconstructions, each of them covers a relative proportion of 10% of the R-R interval, which is already better than the actual temporal resolution. We did not systematically analyze the end-diastolic and end-systolic time points. An advantage over previous studies is that patients with a variety of heart rates and no administration of beta-blockers and thus unaltered ventricular function were examined.

Conclusions. It should not be forgotten that MSCT involves radiation exposure and use of an iodinated contrast agent. Therefore, we believe that MSCT might be used for assessment of LV function in patients with a poor acoustic window in Echo or contraindications to MRI. In case of a clinical indication for noninvasive coronary angiography with MSCT, valid data regarding global and regional LV function can be obtained without additional radiation exposure or contrast agent administration. The assessment of global and regional LV function with MSCT is more accurate than with CVG in comparison with MRI, whereas MSCT is superior to Echo only in the evaluation of global function.

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APPENDIX

To view supplementary video files for Figure 6, please see the online version of this article.